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HIGH RESOLUTION IMAGER (HRI) FOR THE ROENTGEN SATELLITE (ROSAT)

DEFINITION STUDY

Grant NASW-365

FINAL REPORT

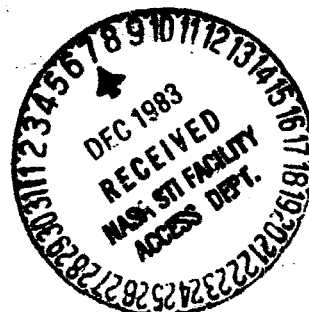
For the Period August 16, 1982, Through February 15, 1983

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**Smithsonian Institution
Astrophysical Observatory
Cambridge, Massachusetts 02138**

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1.0 INTRODUCTION

In May, 1981, SAO submitted an unsolicited proposal to NASA for incorporation of a High Resolution Imager (HRI) in the instrument complement of the Roentgen Satellite (ROSAT), an on-going scientific space program of the Federal Republic of Germany. The HRI to be provided by SAO would, with only minor modification, be essentially the same as the highly successful HRI flown on the High Energy Astronomy Observatory-2 (Einstein). The proposal was submitted in response to the general recognition within the X-ray Astronomy community that inclusion of an HRI in the ROSAT would significantly enhance the scientific yield from that mission. A preliminary cost estimate and program plan were submitted assuming a funding start in December, 1981. This program schedule was compatible with the German program as initially configured.

Since the submission of the May, 1981, proposal, informal technical discussions have taken place between SAO and the Institute for Extraterrestrial Physics (MPE) of the Max Planck Institute for Physics and Astrophysics. One result of this technical interchange is the realization that some modification to the HEAO-2 designs beyond that anticipated in our original proposal will be necessary. These modifications, however, result in a simplification of the HEAO-2 design.

Another result of these continuing discussions between MPE and SAO is a better appreciation of the MPE program schedule. To avoid serious impact to the MPE schedule, it is necessary to provide mechanical models of the HRI sub-systems (front end assembly, central electronics assembly, and detector assembly) to MPE in September, 1982. These mock-ups have provided an accurate representation of the HRI envelope and were used for both fit checks and focal plane configuration studies. The purpose of the definition study is, however,

the definition of interfaces, documentation of design modifications, and submission of a detailed implementation plan.

The following sections of this document summarize the results of the definition study. In addition to providing the fit-check model to MPE, the major effort throughout the study has been to better define the mechanical and electrical interfaces affecting the HRI design, and to establish the requirements for the EGSE necessary to support both the Engineering (EM) and Flight Model (FM) HRI's.

The results of investigations conducted during the definition study have also been incorporated in a revised proposal for a ROSAT HRI (P1087-5-81, Revision #1), submitted to NASA Headquarters in December, 1982. This proposal has since been funded and fabrication of EM and FM HRI's is underway.

2.0 THE ROSAT TELESCOPE

2.1 General Description

The Roentgen Satellite (ROSAT) is being developed as a free-flying X-ray imaging observatory under a Federal Republic of Germany program. The major component of this observatory is a grazing incidence X-ray imaging telescope with photon counting imaging detectors in the focal plane (see Figure 2-1). The spacecraft will be 3-axis stabilized with pointing accuracy and aspect determination consistent with the mirror system resolution. The primary scientific objective of ROSAT is to perform an all-sky survey in the energy range 0.1 - 2 keV with a spatial resolution of 1 arcminute. The sensitivity of ROSAT to point sources is about a hundred times greater than previous surveys, and the expected number of detectable sources should number in the hundreds of thousands. A complete sky survey can be accomplished in a 6-month period. With a predicted life of approximately two years, a large fraction of the mission can be devoted to follow-up pointed observations of sources detected in the survey or for pointed studies of interesting objects. At energies below 1.5 keV, the sensitivity of ROSAT is equal or greater than that of the Einstein Observatory. Therefore, many of the studies that Einstein either initiated or suggested can be carried out very effectively by ROSAT.

2.2 The Mirror System

The mirror system consists of four nested Wolter type I mirrors made of Zerodur (Figure 2-2). The mirror surfaces will be coated with either gold or nickel to enhance their reflectivity. The diameter of the outer element is 80 cm and the total geometrical collecting area is 1250 cm². The effective area (the product of the reflectivity and the geometrical area) is shown in Figure 2-3. At 1 keV (12 Å) the effective collecting area is 500 cm² for

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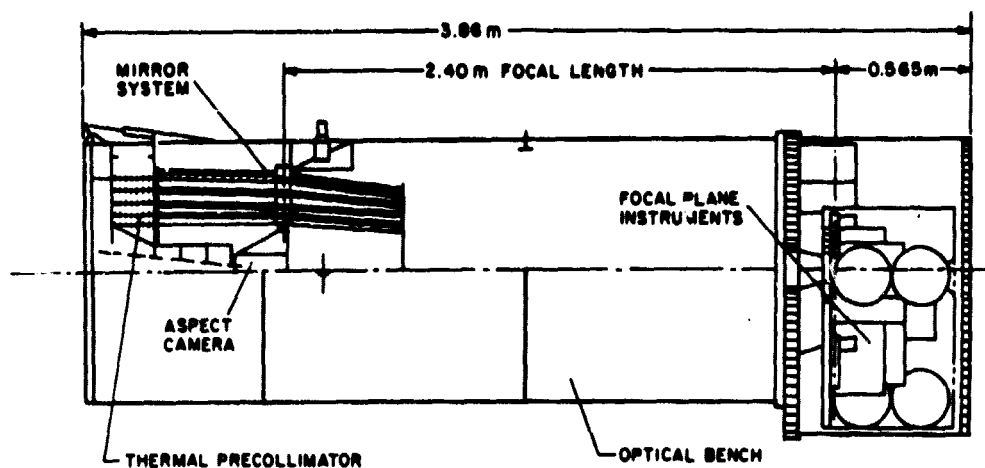
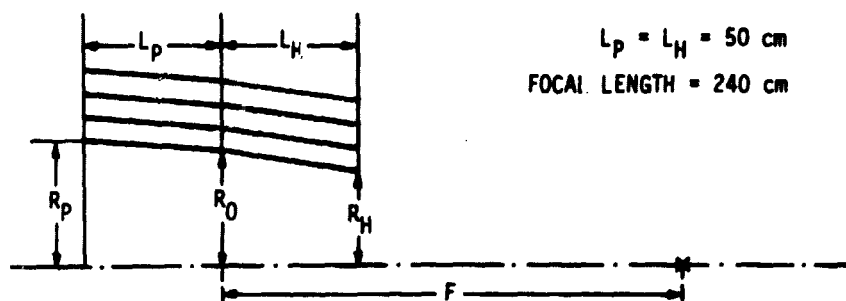
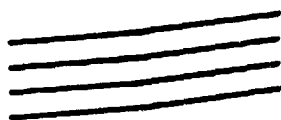


FIGURE 2-1 DIAGRAM OF ROSAT TELESCOPE



$$L_p = L_H = 50 \text{ cm}$$

$$\text{FOCAL LENGTH} = 240 \text{ cm}$$



MIRROR PAIR	R_p (cm)	R_0 (cm)	R_H (cm)	α°
1	40.00	38.08	32.09	2 ⁰ 25
2	34.47	32.81	27.65	1 ⁰ 94
3	29.28	27.87	23.48	1 ⁰ 65
4	24.40	23.22	19.26	1 ⁰ 38

* α : mean grazing angle

FIGURE 2-2 MIRROR ASSEMBLY CROSS-SECTIONAL VIEW

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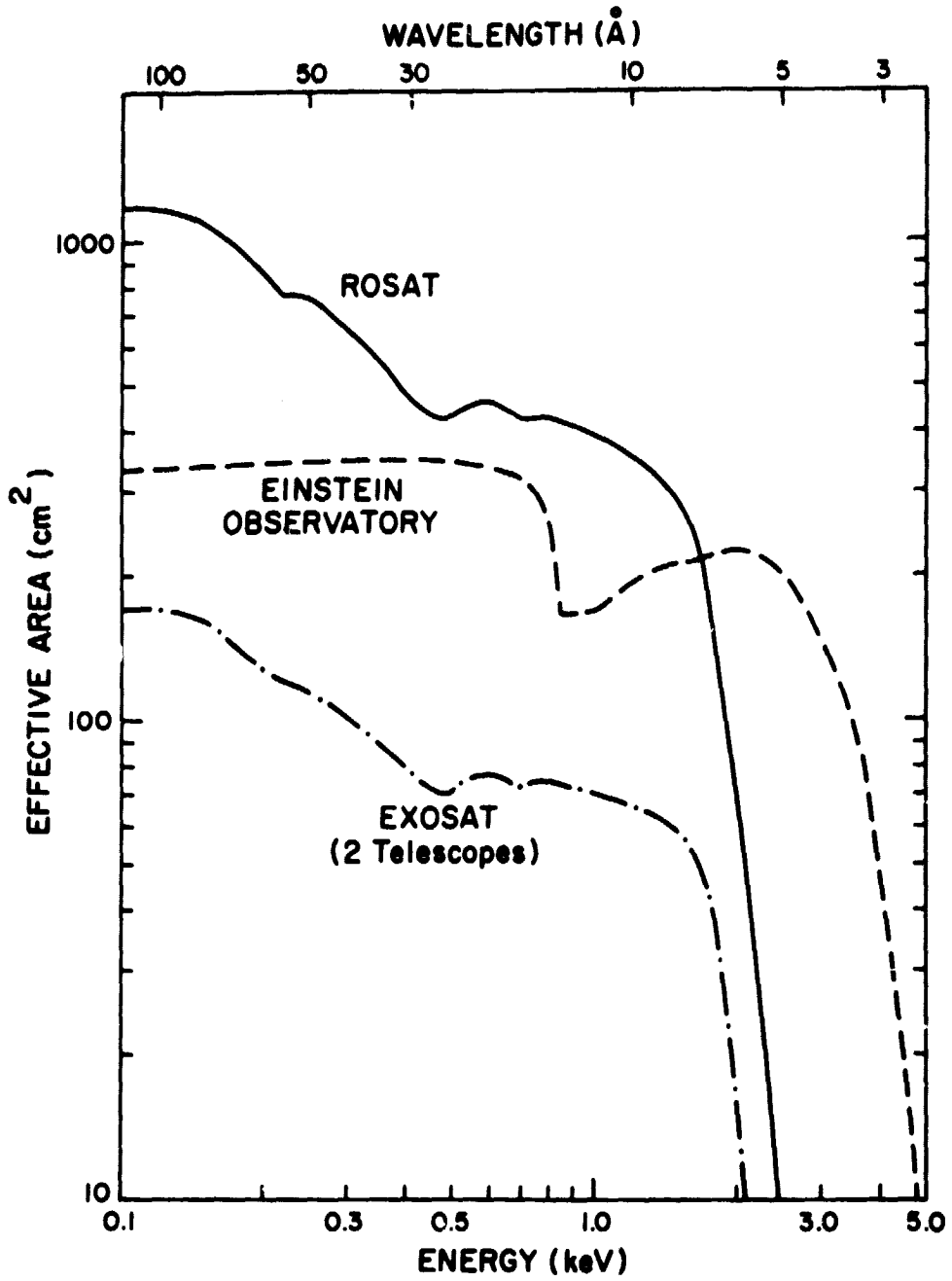


FIGURE 2-3 EFFECTIVE AREA vs ENERGY

on-axis rays. The angular resolution of the mirror system for on-axis rays is 5 arcseconds (FWHM). Table 2-1 gives a summary of the characteristics of the mirror system and compares them to the Einstein Observatory and EXOSAT.

2.3 Focal Plane Instruments

The focal plane assembly (Fig. 2-1) permits the placement of three different detectors at the focal plane of the mirror assembly. The detector for the all-sky survey will be a two-dimensional position sensitive gas proportional counter (PSPC) with a field of view of 2° and a position resolution of better than 0.7 mm (1 arcminute) over the energy range of interest (0.1 - 2 keV). For redundancy, an identical PSPC will be provided as part of the instrumentation complement.

A third detector will be a high resolution two-dimensional imaging detector of the EINSTEIN HRI type. This will provide a very important complement to the two moderate resolution detectors. A high resolution imager (HRI) will obtain arcsecond positions of the sources discovered in the all-sky survey. Without this positional accuracy, the search for optical counterparts will be extremely laborious. The positions provided by a moderate resolution PSPC will have large uncertainties and there will be several possible optical candidates within the error circle. An HRI will also enable a continuation of the high spatial resolution studies begun by the Einstein Observatory of supernova remnants, globular clusters, nearby galaxies, active galaxies, and clusters of galaxies.

Table 2-1 - Telescope Characteristics

	<u>EXORAT</u>	<u>ALINSTEIN</u>	<u>ROSAT</u>
Outer diameter of mirror assembly	0.3 m	0.6 m	0.8 m
Number of nested pairs	2	4	4
Focal length	1.09 m	3.4 m	2.4 m
Plate scale	5.3 $\mu\text{m}/\text{arcsec}$	14.6 $\mu\text{m}/\text{arcsec}$	11.6 $\mu\text{m}/\text{arcsec}$
Field of view	1.5°	1.25°	2°
Telescope resolution (FWHM)	14 arcsec	4 arcsec	5 arcsec
Geometric area	180 cm^2 (2 tsl.)	500 cm^2	1250 cm^2
Passband	6-300 Å	3-100 Å	6-100 Å
Minimum detectable point source strength	1 x 10 ⁻¹²	4 x 10 ⁻¹³	2 x 10 ⁻¹³

0.1-3 keV band; photon number spectrum: power law with index of 1.4, cut-off at 0.25 keV; 10³ seconds observation with Imaging Proportional Counter.

3.0 SCIENTIFIC OBJECTIVES OF THE HIGH RESOLUTION IMAGER ON ROSAT

3.1 Sky Survey

All sky surveys have traditionally been a foundation of astronomy. At radio wavelengths, the 3CR and 4C catalogues of the northern sky enable the study of unbiased populations and have guided the programs of the newer more sophisticated radio telescopes by finding interesting objects. At optical wavelengths the Palomar, ESO and UK Schmidt surveys play a similar vital role.

At X-ray wavelengths all sky surveys have been made using the Uhuru, Ariel V, and HEAO-1 satellites. The most sensitive of these have a limiting flux of about 2×10^{-11} erg cm⁻²s⁻¹ (1-3 keV equivalent). These early surveys have shown that the log N-log S relation (for extragalactic sources) to these flux levels is consistent with Euclidean geometry, and have enabled the determination of some luminosity functions. The two major classes of extragalactic X-ray sources detected at these flux levels are active galactic nuclei and clusters of galaxies. Among the fundamental discoveries made in these first all sky surveys are: binary X-ray sources, X-ray bursters, extended emission from an intracluster medium, and X-ray emission from active galactic nuclei.

One of the primary ROSAT mission objectives is to carry out an all sky survey at limiting sensitivity ~ 2 orders of magnitude fainter than previously possible. With a position sensitive gas proportional counter (PSPC), and an observational time of ~ 1000 seconds, the ROSAT survey will reach a sensitivity near 10^{-13} erg cm⁻²sec⁻¹ (corrected to the 1-3 keV band). At this flux limit about 200,000 sources should be detectable, of which, one third to one half will be galactic stars and the remainder associated with extragalactic objects. Based on the experience gained with the Einstein Observatory medium and deep surveys, identification of sources at low flux levels will be difficult with PSPC location uncertainties. Typically, several optical candidate objects will

be present within each source location region. In many cases, the proper identification of an X-ray source will not require detailed optical studies as an obvious counterpart is present. However, the experience with Einstein surveys has been that a significant number of sources require either detailed optical studies to uncover the signature of an X-ray source, or better positions to reduce the number of candidates, or both. The typical optical apparent luminosity of counterparts to X-ray sources at the ROSAT survey limit is faint ($\text{mag.} \geq 17$), thus long observations with large telescopes are needed for optical follow-up. The use of an HRI to locate ROSAT survey sources accurately, and thereby facilitate identifications, would clearly be important in carrying out the construction of a meaningful catalog of sources.

Observation times ranging from 10^3 to 10^4 seconds are required with the HRI to detect these sources. Thus only a selected fraction of all sources could be observed with this detector. One possible technique would be to use the HRI to obtain a complete survey in a specific region of the sky. Another approach would be to follow up many unidentified PSPC sources as possible, with about a 6-month lapse between the two observations to allow for preliminary optical work and solar constraints in X-ray telescope pointing. In either case, a rapid turnaround of the ROSAT data is required to allow planning of observations.

In addition to improving the locations of X-ray sources and aiding in identifications, the high resolution capability of an HRI on ROSAT expands the types of scientific studies which can be carried out. We point out that in the time frame of ROSAT, there will be no other X-ray satellite capable of carrying out such high angular resolution studies. Below we give examples of some scientific studies which can be carried out with ROSAT making particular use of a high resolution detector.

3.2 Other Scientific Investigations

Stellar Survey. Einstein studies of stellar emission have shown that virtually all types of stars are X-ray sources. This was an unexpected result and has led to a review of theoretical models for stellar structure and energy transport. Continued observations of X-ray emission from stars is necessary to sort out the correlations of various physical properties such as magnetic field, rotation rate, spectral type, etc., with X-ray luminosity. Against this reservoir of data, revised models of stellar structure and energy transport can be tested and refined. In order to determine stellar X-ray luminosity functions, unambiguous identifications are required. In many cases (~20%), the stars will be in visual double systems with separations of several arc seconds. In such cases, the high resolution detector is needed to determine the level of X-ray emission for each star. A proposed correlation between X-ray emission and stellar rotation can be studied through observations of stars in close binary systems, which are phase locked so that the stellar rotation periods are well known. In such cases a high resolution detector is essential.

Globular Clusters. The X-ray sources near the center of globular clusters can be "weighed" by determining how near the center they are on average. All of the previously known X-ray globular clusters have been observed with the Einstein Observatory. The results thus far suggest that the X-ray sources are not supermassive black holes as was previously speculated but are probably 1-2 M_{\odot} neutron stars. However, with the present small sample size, the constraints on the mass are not very tight. An all sky survey would probably double the sample size to about twenty objects. Five new globular cluster X-ray sources have already been discovered with Einstein, but have not been observed with the HRI because they were found too near the end of the mission. With this larger sample it would be possible to more accurately "weigh" the globular cluster X-ray sources. Also, these sources can be used to probe the nature of

the cluster potential wells. This would give unique insights into the nature of the potential of self-gravitating systems.

Supernova Remnants (SNRs). With ROSAT, the studies of the spatial structure of supernova remnants begun with the Einstein Observatory can be continued and extended. Searches for changes in the X-ray structures of young SNRs can be performed with a 6 to 7 year baseline. Such changes could result from proper motions of the remnant, and/or from intensity changes of the various wisps, knots, and bright spots that make up the remnant. These studies will help elucidate the details of heating mechanisms and the interaction of ejected material with the interstellar medium, as well as determine the ages of the remnants.

The HRI can also be used to examine galactic objects detected by the PSPC, but only barely resolved by it to determine if these objects are in fact supernova remnants. These studies would yield a complete X-ray selected sample of Galactic supernova remnants, which can be compared with a similar sample of LMC objects. Such comparative studies can be used to search for systematic differences in explosion rates, remnant luminosities, and expansion rates. With a complete sample of remnants the fraction of supernovae that leave behind a compact object (neutron star) can be determined.

Galactic Nuclei. Many normal galaxies are observed to be X-ray sources, some emit at a level in excess of 10^{41} erg s⁻¹ in the 1-3 keV energy band. These otherwise undistinguished galaxies (optically dull galaxies) can be identified in the course of the ROSAT all sky survey, and followed up with subsequent HRI studies. This will permit the site of X-ray emission to be determined (nuclear versus disk). Similarly for normal galaxies, which have X-ray emission comparable to our Galaxy, HRI observations can be used to separate the nuclear component of emission from that due to individual galactic sources. These data can be used for correlations of nuclear X-ray emission with

other galactic morphological parameters.

Active Galaxies. Each of the known classes of active galaxies of active galactic nuclei has been detected in the X-ray band. These include Type I and Type II Seyfert galaxies, radio galaxies, BL Lacertids and the QSO's. In several cases ''jet'' like structures have been detected and mapped (e.g. Centaurus A and M87). The interpretation of an X-ray jet as a stream of relativistic particles may explain the energy source for the radio lobes associated with Cen A. More detailed observations of this class of structure in a variety of sources will be needed to determine if this is a universal phenomenon.

There is a strong correlation between the presence of X-ray emission (and probable structure) and radio emission with an inverted spectrum (i.e., millimeter emission). This can be followed up with ROSAT-HRI observations of radio selected galaxies. In general, the X-ray observation of compact structures (i.e., jets, in active galaxies) extends the spectral range of data, and significantly constrains models for the acceleration of relativistic particles in these sources. In addition, the X-ray observations can provide information on how the radio structures are confined, since they can determine or limit the gas density of the ambient medium via searches for thermal bremsstrahlung emission, and the magnetic field within radio lobes via searches for inverse Compton emission.

Clusters of Galaxies. The study of clusters of galaxies is greatly aided by the high angular resolutions afforded by the HRI. With ~10 arc second resolution, the structure of the gas clouds around individual galaxies in the nearby Virgo, Centaurus, and A1060 clusters can be studied. Only about 5 such galaxies have been observed in the Virgo cluster with the Einstein Observatory, and another 10 could have been observed were time available. HRI observations of galaxies in the Centaurus and A1060 clusters were just beginning. These high

resolution observations are required for the study of details of the galaxy stripping process, which is presumed to be the mechanism for generating the hot X-ray gas observed in the clusters. High resolution studies of the central galaxies in the Virgo and Perseus clusters show the pattern of the accreting flows of matter that contribute to the growth of the cD galaxies often found at the center of clusters. The ROSAT HRI will enable more examples of this phenomenon to be examined.

The observation of somewhat more distant clusters, similar to A1367, will make possible the study of gas clouds trapped by individual galaxies that are not at the center of the cluster. If the gas clouds are gravitationally bound by the galaxies, high resolution X-ray observations may be used to trace the gravitational potential, and thereby enable the study of the mass distribution of these galaxies. This will shed new light on the existence and nature of massive dark halos in galaxies. Since only two clusters have been observed in sufficient detail with the Einstein HRI to make these studies, it is clear that a ROSAT HRI will make a significant contribution. Additionally, high resolution observations of a large number of extended galaxy sources, in a variety of cluster environments, should allow a determination of the effects of pressure confinement of hot gas.

The detailed properties of distant clusters ($Z > 0.1$) can only be observed with high angular resolution instruments because the sizes of these clusters are of order one arcminute. Studies of these objects are important to the understanding of the evolution of clusters of galaxies. Also since evolutionary changes of apparent cluster properties are of the same order as the geometrical changes used for closure tests, the evolution of clusters must be understood in order to use these classical tests to assess whether the Universe is open or closed.

4.0 THE HIGH RESOLUTION IMAGING DETECTOR (HRI)

4.1 Summary Description

The two-dimensional high resolution imaging detector for the ROSAT mission is a copy of the HEAO-2 (Einstein Observatory) High Resolution Imaging instrument (HRI) (Figure 4-1). This instrument uses a pair of cascaded microchannel plates (MCPs) as an X-ray sensitive photocathode surface and imaging photoelectron multiplier, and a crossed-wire grid as a two-dimensional position-sensitive charge detector (Figure 4-2). Position determination is accomplished by electronic interpolation between the coarse grid wires (0.2 mm spacing). The detector provides the arrival time within 8 μ s and position (34 μ m, FWHM) of each X-ray event which occurs within the field of view (25.4 mm diameter).

The MCP photocathode surface is shielded from ultraviolet light and ions by a thin, metalized self-supporting plastic filter. The measured, in-flight, combined diffuse X-ray, particle, and instrumental background of the Einstein HRI is ~ 0.5 counts $\text{cm}^{-2} \text{s}^{-1}$.

Given the plate scale of the ROSAT telescope of 11.6 $\mu\text{m}/\text{arcsec}$, the angular resolution of an HRI is 3.0 arcsec, FWHM (the ROSAT mirror assembly resolution is 5 arcsec, FWHM), and the field of view is 36 arcmin diameter. Summary characteristics are shown in Table 4-1.

Table 4-1 - Summary of Einstein HRI Performance Characteristics

Spatial Resolution (FWHM)	34.4 μm (3.0 arcsec for ROSAT)
Field of View (dia.)	25.4mm (36 arcmin for ROSAT)
Temporal Resolution	8 μs (62 μs for ROSAT)
Background Counting Rate (in-orbit)	$\sim 0.5 \text{ cts cm}^{-2} \text{ s}^{-1}$

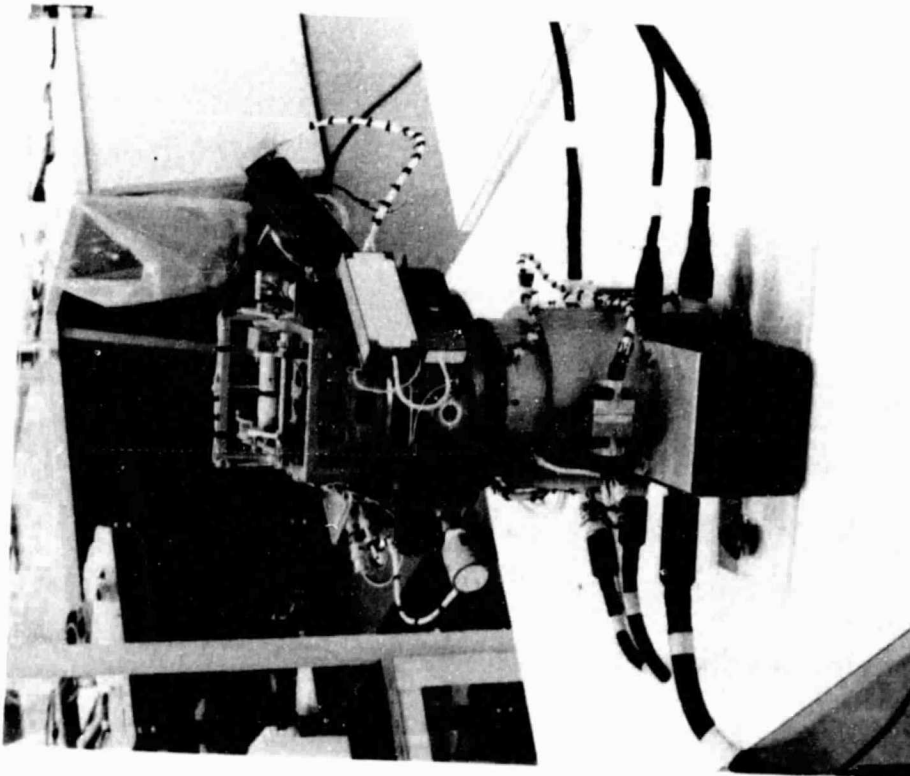


Fig 4-1a Photograph of HEAO-2 HRI

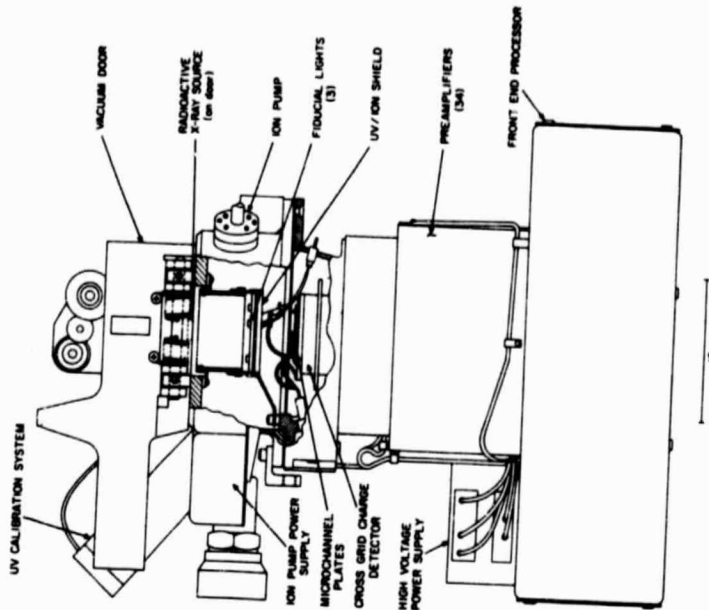


Fig 4-1b Side view of HEAO-2 HRI

Fig 4-1 HEAO-2 HRI

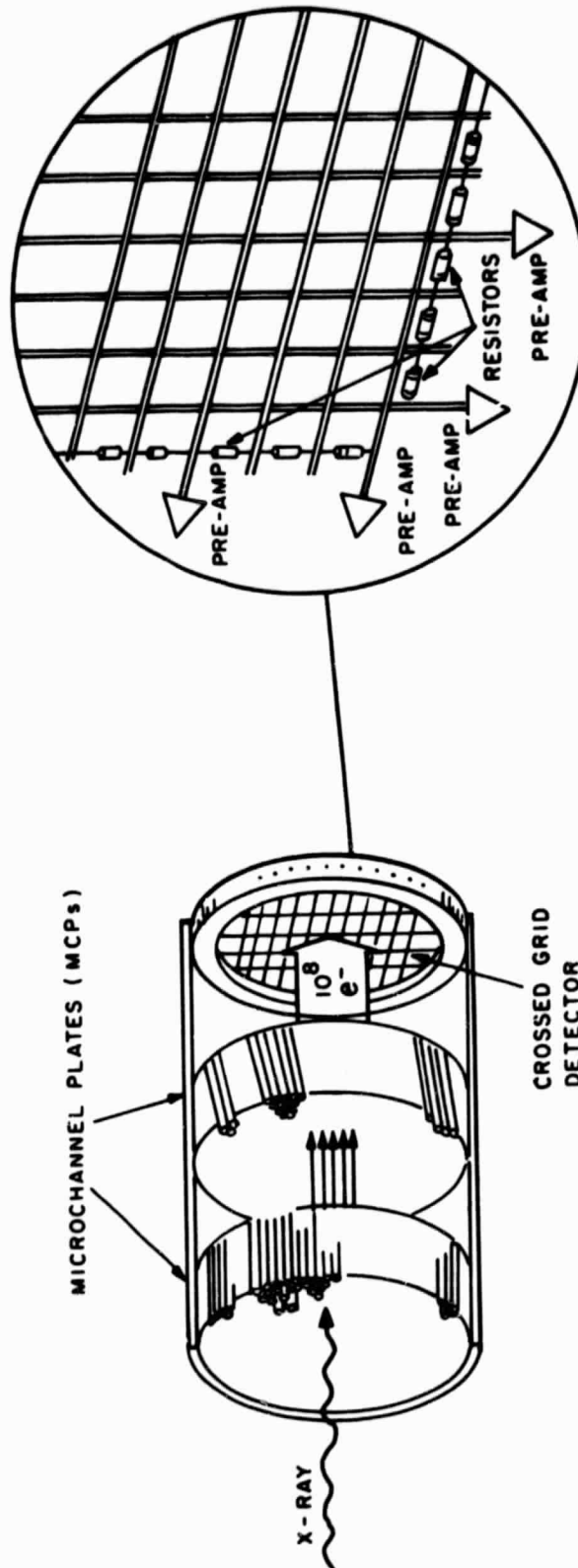


FIGURE 4-2 PRINCIPLE OF OPERATION OF HRI

4.2 HRI System Configuration

The HRI which we will be providing to the ROSAT is to be as similar as possible to the HEAO-2 (Einstein) HRI. All nomenclature and system organization developed in the course of the HEAO-2 program will be retained both for the convenience of familiarity and the ability to utilize existing HEAO-2 documentation.

4.3 HRI Hardware Configuration

The HRI consists of two major assemblies: the Detector Assembly and a Command and Data Electronics Assembly (CDEA), both of which are mounted in the focal plane assembly. The CDEA is functionally equivalent to the HEAO-2 Central Electronics Assembly (CEA), but since on ROSAT our CDEA is not ''central'' and there already is a Central Electronics Assembly, the name has been changed to avoid confusion.

4.3.1 Detector Assembly

The Detector Assembly consists of an Aft Assembly and a Forward Assembly. The Aft Assembly includes the X-ray detection elements and most of the detector assembly electronics: a cascaded pair of MPCs, the crossed-grid charge detector (CGCD), UV/Ion Shield, high voltage power supplies, and processing electronics. The low voltage power supply is mounted to the Aft Assembly.

The Forward Assembly includes a stainless steel housing which mates with the Aft Assembly to form a vacuum cavity for the detector elements. Attached to this housing is a valve for initial pump down, an ion pump and ion pump power supply for maintaining a high vacuum, an ultraviolet calibration system, and a remotely controlled vacuum door. The vacuum door is equipped with a redundant opening mechanism. An X-ray source is attached to the inside of the vacuum door to stimulate the detector during ground testing.

4.3.2 Command and Data Electronics Assembly (CDEA)

The Command and Data Electronics Assembly (CDEA) contains electronics which complete event data processing with respect to digital position, amplitude, and time. The electronics also include a slave unit which buffers and distributes commands from the MPE electronics to the appropriate HRI subsystems. Additional "secondary science" rate data and analog housekeeping data are processed.

Primary science data are merged with secondary science and command status indicators into the High Rate data stream by means of control logic and a local buffer memory. (System details and requirements are totally different from those of HEAO-2 and a new design is required for this portion of the HRI - see Section 4.5.)

4.4 Calibration System

The HRI instrument contains two calibration sources, an X-ray source (X-ray response), and a U-V calibration system (position response). A fiducial light system is provided for use by the spacecraft aspect system if desired.

The HRI calibration system consists of a radioactive X-ray source mounted on the Vacuum door and a U-V optical system which projects a geometric pattern on the detector face. The X-ray source provides a monitor for the MCP gain characteristics. The U-V optical system provides a means of calibrating the HRI position encoding system.

4.5 Modifications to HEAO-2 Configuration

Although the final details of the interface between the HRI and the ROSAT are not complete, the general nature of the requirements has been determined and in most cases a detailed understanding does exist. Some modification to the

HEAO-2 configuration is required in order to integrate the HRI into the ROSAT.

Areas involved are:

1. Detector Assembly

1.1 Relocation of vac-ica pump and supply, and U-V cal and supply to different angular positions.

1.2 Modification of vacuum door and door drive assembly.

1.3 Location of LVFS on front-end processor.

2. Command and Data Electronics Assembly (CDEA)

2.1 Data interface electronic redesign

2.2 Command interface electronic redesign

2.3 CDEA Housing Redesign

3. Ground Support Equipment

3.1 BGSE - Change to accommodate new interface requirements, decommutate new data format, and incorporate Einstein S/W modules into data evaluation routines.

3.2 MGSE - Change to accommodate ROSAT instrument insertion/exchange concept.

The relocation of the U-V calibration assembly requires that a new mask be generated. Existing HEAO-2 software will be used to define the modified geometry mask pattern required.

The areas related to the Detector Assembly and the CDEA are examined in this section. The GSE areas are discussed in Section 7.0.

4.5.1 Detector Assembly

The HRI Detector Assembly has a number of radial appendages which are mounted to the center cylindrical housing. It has been established that the

orientation used on HEAO-2 is not suitable for the ROSAT by reason of significant physical interference with the ROSAT focal area structure. Several configurations which will "fit" have been identified. One such configuration is shown in Fig. 4-3.

The vacuum door assembly must be changed. The redundant one-time opening mechanism used on HEAO-2 results in interference with the ROSAT structure. Some effort has been expended without success in identifying alternative approaches to obtaining a redundant opening capability. Consequently, significant reliability and design analyses will be required to ensure reliable operation of the single door drive. We will review the electronic drive and the door drive logic. Almost certainly a vented cover will be placed over the open drive. Although the HEAO-2 primary door drive operated successfully a number of times and never experienced failure, this is an area of concern which will receive in-depth study and review early in the program.

For a number of reasons, it is desirable to mount the Low Voltage Power Supply on the outside of the front end processor housing of the Detector Assembly. This is also a departure from the HEAO-2 configuration. Some structural modification will be required.

4.5.2 Command and Data Electronics Assembly (CDE/A)

Two major electronic design changes are required to accommodate the ROSAT. The first relates to the primary high rate data interface. The spacecraft data handling system is designed in such a way that the HRI requires a buffer memory of about 1,000 bits to store a complete ROSAT format. Additional control logic is required to implement both the set-up of HRI data into the memory and the transfer out of the memory to the spacecraft.

The second electronic design change relates to the command interface. All HRI commands are initiated by the MPE micro-computer system to an MPE-designed

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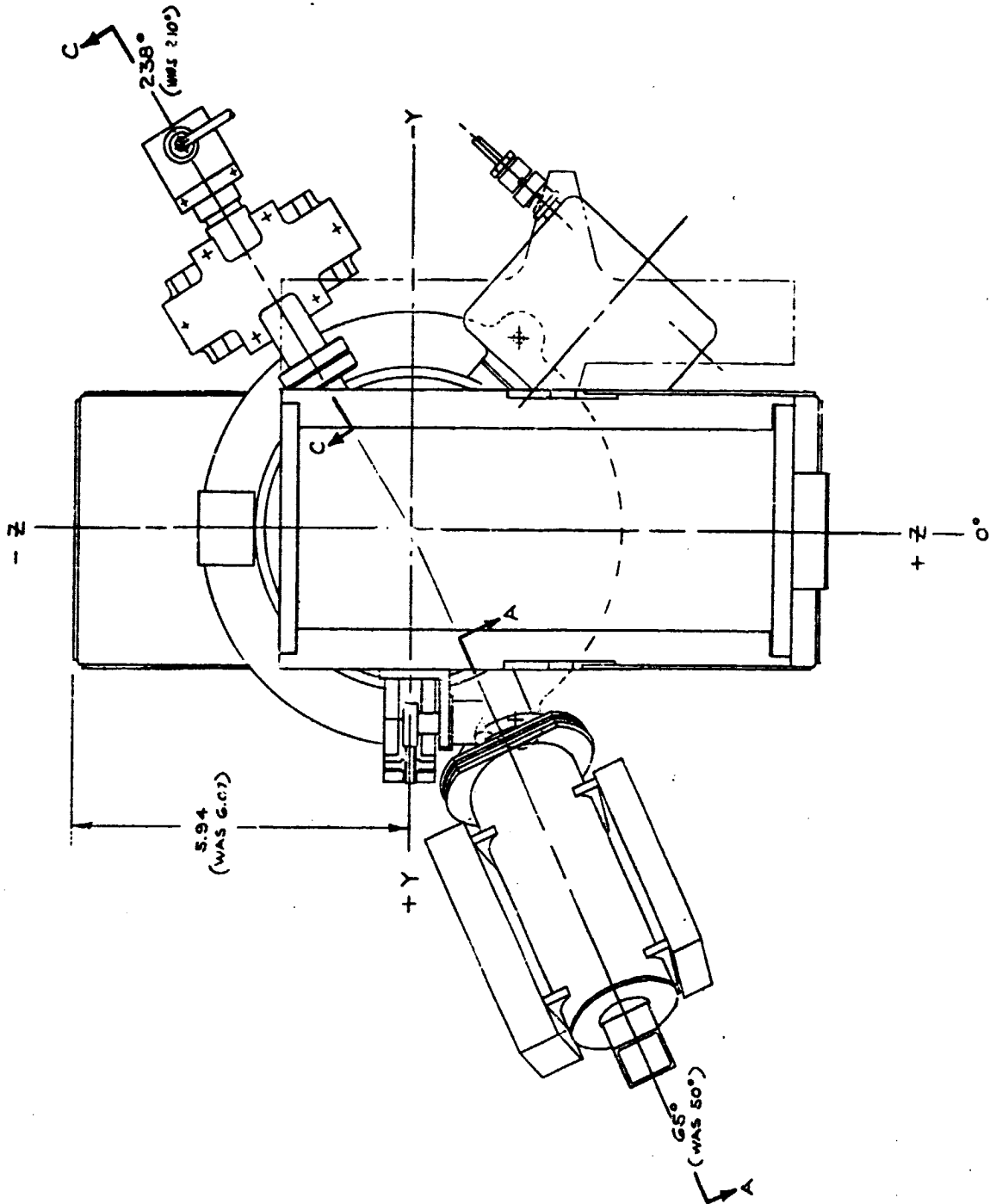


FIGURE 4-3 REQUIRED MODIFICATIONS

"slave" circuit which is located in the CDEA. This slave receives a command word. New logic will decode and implement each command. Both the number of functional commands and command word complexity have been reduced relative to HEAO-2.

Because of stringent space limitations, it is necessary to re-package the CDEA. Although the internal card modules will use the same mechanical design (and in many cases, the same electrical design) as was used on HEAO-2, the housing in which they are contained and interconnected and which mounts to the ROSAT is a new design. The general allowable outline of this unit is shown in Fig. 4-4.

4.6 ROSAT Interfaces

Discussions with MPE and DFVLR have established preliminary interface requirements for the HRI. Additional clarification and definitions will be accomplished within 30 days of contract award.

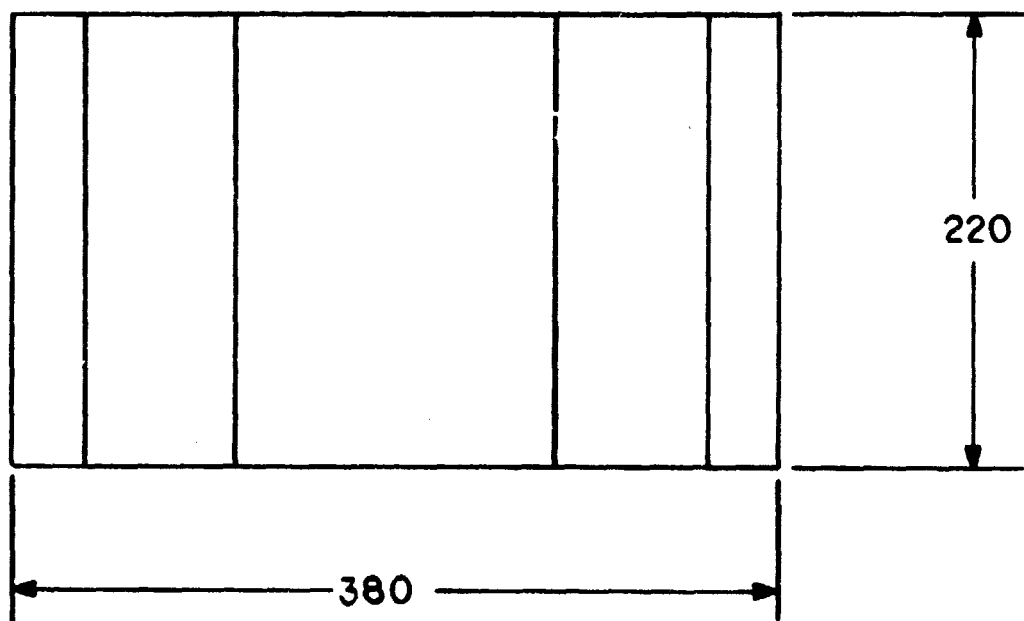
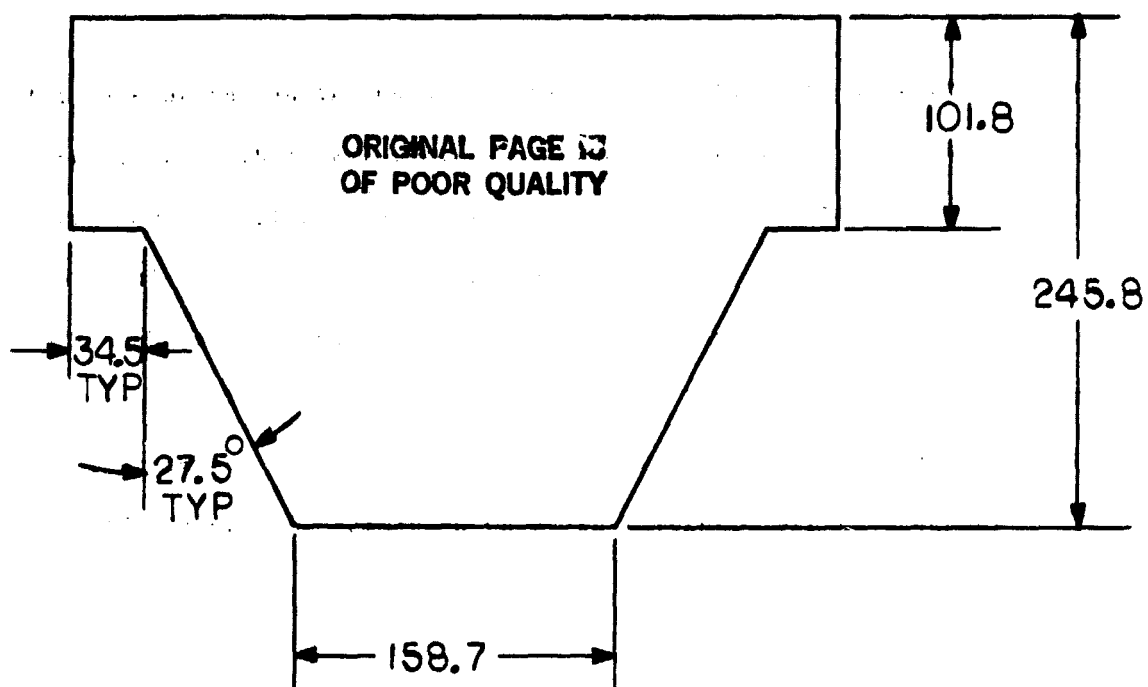
4.6.1 Power, Weight, and Temperature

The basic HRI requirements are defined below:

Power:	9.7 watts operating
	8.6 watts stand-by
Weight:	Detector Assembly 17.7 kg
	CEA 22.3 kg
Temperature:	-10°C to + 30°C operating
	-15°C to + 40°C storage

4.6.2 Protective Systems

The HRI must be protected against operation in the high radiation environment associated with South Atlantic Anomaly (SAA) encounters and against operation at pressures above 10^{-5} torr.



ALL DIMS IN MM

FIG 4-4
COMMAND AND DATA ELECTRONICS ASSEMBLY
(MAXIMUM VOLUME SHOWN)

In the case of an SAA encounter, provision exists for a commanded high voltage reduction either automatically from an external SAA detector or by computer programmed command. Such commands, either programmed or automatic, must be generated external to the proposed HRI.

The HRI high voltage supply protects against breakdown which can occur at pressures above 10^{-5} torr. The supply senses load current. If the current exceeds a predetermined threshold, the high voltage turns off automatically. Once turned off, it must be commanded on by an external turn on command.

5.0 TEST AND CALIBRATION OF THE HRI

5.1 Introduction

The testing performed on the ROSAT HRI will verify that it is functionally identical to the HEAO-2 instrument. The same procedures used for the HEAO program will be used on this program. In the following we refer to the relevant HEAO procedure (P) or test plan (TP) numbers. As the instrument reaches the final stages of assembly, these tests will also provide a calibration baseline for the proper interpretation of the full-up ROSAT calibration data and the science data gathered in orbit.

5.2 Subassembly Level Tests

5.2.1 Microchannel Plates

Microchannel plates (MCPs) will be burned-in, tested, and evaluated at the SAO test facility (Figures 5-1 and 5-2) according to TP 145-271. In this series of tests the MCPs are tested in pairs. The front plate is illuminated with monochromatic X-rays of selectable energies and angles of incidence and the total charge released by the rear plate is collected and measured. A calibrated proportional counter measures the X-ray flux incident on the channel plate assembly. This series of test determines:

- (1) gain vs. applied high voltage,;
- (2) quantum efficiency vs. high voltage, angle of incidence, and incident X-ray energy,;
- (3) dark count rate vs. high voltage.



Fig 5-1 Quantum Efficiency Test Facility

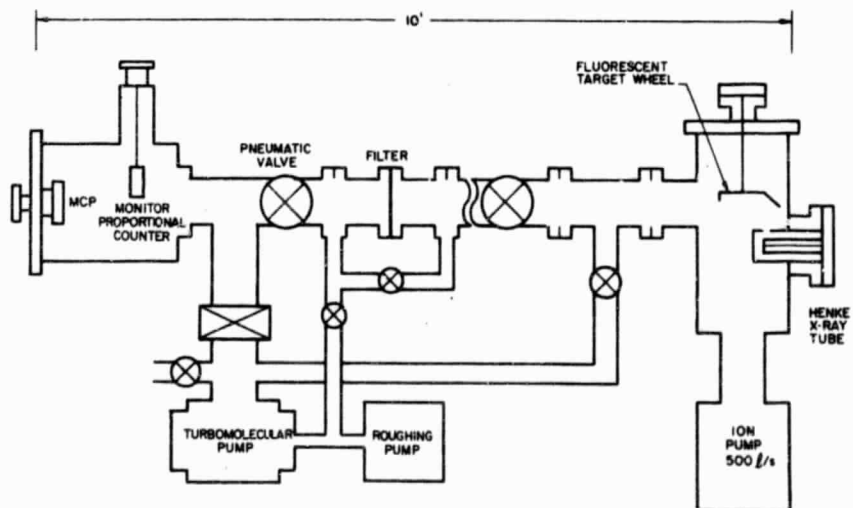


Fig 5-2 Quantum Efficiency Test Facility Schematic

5.2.2 UV Source

We will use TP145-323 to screen the UV light source bulbs and TP145-322 to screen the UV light source high voltage power supplies.

5.2.3 Mechanical and Electrical Subassemblies

On the HRAO-2 program, electrical and mechanical subassemblies were inspected and tested prior to assembly into the next higher subassembly wherever such inspection/test was cost-effective in terms of both incremental inspection/test costs and potential loss if non-conformance were to be discovered at the next highest level.

The HRAO-2 inspection and electronic test procedures will be used wherever applicable. Mechanical inspection will be performed as on HRAO-2. Electronic test will be performed at the single card level and higher for the HRI Detector Assembly.

In the case of the CRA, tests will be performed at the module level and higher. (Each module is composed of two printed circuit cards connected to a common interface connector.) Frame wiring will be verified by resistance measurement.

The forward vacuum assembly mechanism and seal will be tested as a complete subsystem.

5.2.4 UV/Ion Shield

UV/Ion shields will be screened for pinholes and their permeability to UV light and X-rays.

5.3 Assembly Level Tests

5.3.1 X-Ray Tests

The partially completed detector assembly (MCPs, CGCD, and front-end processor) will be tested at the HRI test facility (Figs. 5-3 and 5-4) at SAO according to procedure CFA/HEA-76-142.

This sequence verifies detector operation. It will also define the baseline calibration with regard to:

- (1) spatial resolution,
- (2) spatial variation of background,
- (3) spatial uniformity of quantum efficiency, and
- (4) level of geometric distortion of the detector.

These data will enable us to decide whether the selected MCPs meet the imaging specifications at a time when they can be replaced easily, if necessary.

5.3.2 UV/Ion Shield Tests

Tests will be performed on the detector assembly with the UV/Ion shield in place to determine the sensitivity to UV light, ions, and electrons. UV light, ions, and electrons will be provided by auxiliary sources mounted to the HRI test facility.

5.3.3 UV Calibration System

To calibrate the HRI's position encoding system, a pattern of ultraviolet-light is projected onto the top microchannel plate surface by the UV calibration system. A computer program developed for HEAO will be used to generate a calibration map.

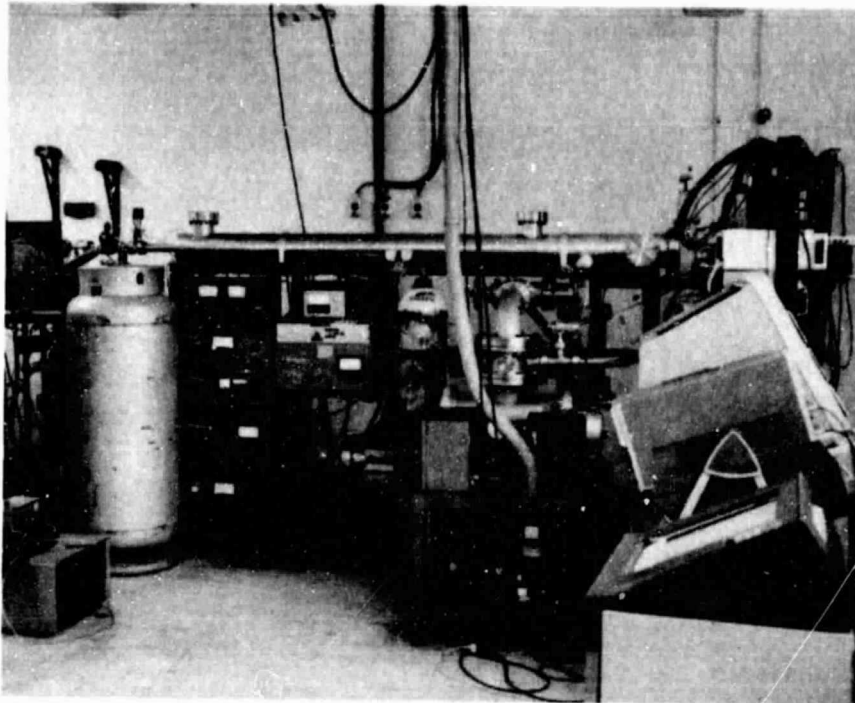


Fig 5-3 HRI Test Facility

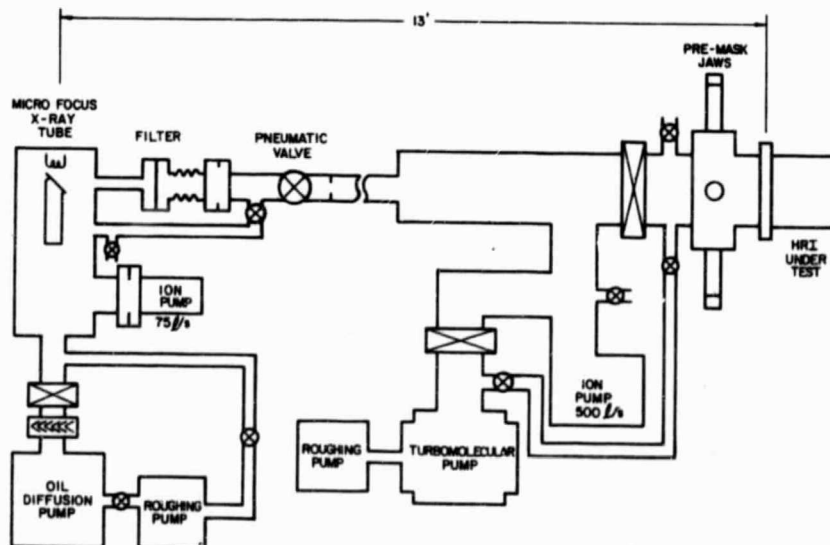


Fig 5-4 HRI Test Facility Schematic

5.3.4 Command and Data Electronics Assembly

Integration of tested modules into the CDEA and verification of operation of the command and power system will be accomplished using essentially the same procedures as were used on the HRAO-2 program. Because of consolidation of the HRAO-2 CDEA configuration for this program, the procedural details will require some minimum modification.

5.3.5 HRI Functional Tests

The HRAO-2 HRI Functional Test procedures will be slightly modified to provide a standard functional test sequence for the ROSAT HRI instrument.

The standard test sequence will exercise the HRI instrument to the maximum extent possible without opening the vacuum door and examine the HRI response in a detailed systematic manner.

We anticipate repeating these tests many times prior to shipment to MPI/MPE. This will provide operating life on the instrument which will tend to uncover marginal components and/or conditions.

A baseline characteristic of the instrument will be established, and continuous evaluation of test data together with trend analysis of the total data set will be carried out in order to assure that there are no changes in detector performance.

5.3.6 Environmental Tests

The environmental tests of the completed assemblies (detector and CEA) include a vibration test, conducted according to P145-324, and a thermal vacuum test, conducted according to TP145-332. Since the HRAO instruments have already been tested to qualification levels, these tests will be done at flight levels to check workmanship.

6.0 OBSERVATORY LEVEL TESTS

Upon completion of post shipment checks in Germany, integration of the HRI into the ROSAT focal plane assembly and test of its operation through the ROSAT interface can begin. This is expected to be followed by test and calibration of the total ROSAT telescope in the MPI/MPE X-ray Test Facility. Not only will the HRI/mirror assembly be calibrated in this activity, but these tests can be used to determine the X-ray performance of the ROSAT X-ray mirror assembly alone.

6.1 HRI Tests

A series of sequential tests and inspections will be carried out as the HRI is integrated into the ROSAT HRI focal plane assembly. Once mechanical interfaces are verified, electrical testing will begin. This testing relates to the power, command/control, and data interfaces.

As long as accessibility is maintained, the EGSE can be used directly and independently with the HRI. When electrically connected to the ROSAT, data are merged into the total ROSAT data format. This data stream is then provided to the EGSE so EGSE software can be used directly in the analysis and display of HRI performance. Test of both the hardware and software associated with this interface are considered HRI tests.

A preliminary functional test procedure will be used to accomplish integration and check-out. Upon completion of initial check-out of the integrated HRI, a baseline functional test procedure will be used to establish a baseline for HRI performance in the ROSAT focal plane. This will be compared with the HRI functional baseline established previously. Differences, if any, will be reviewed to determine cause and need for corrective action.

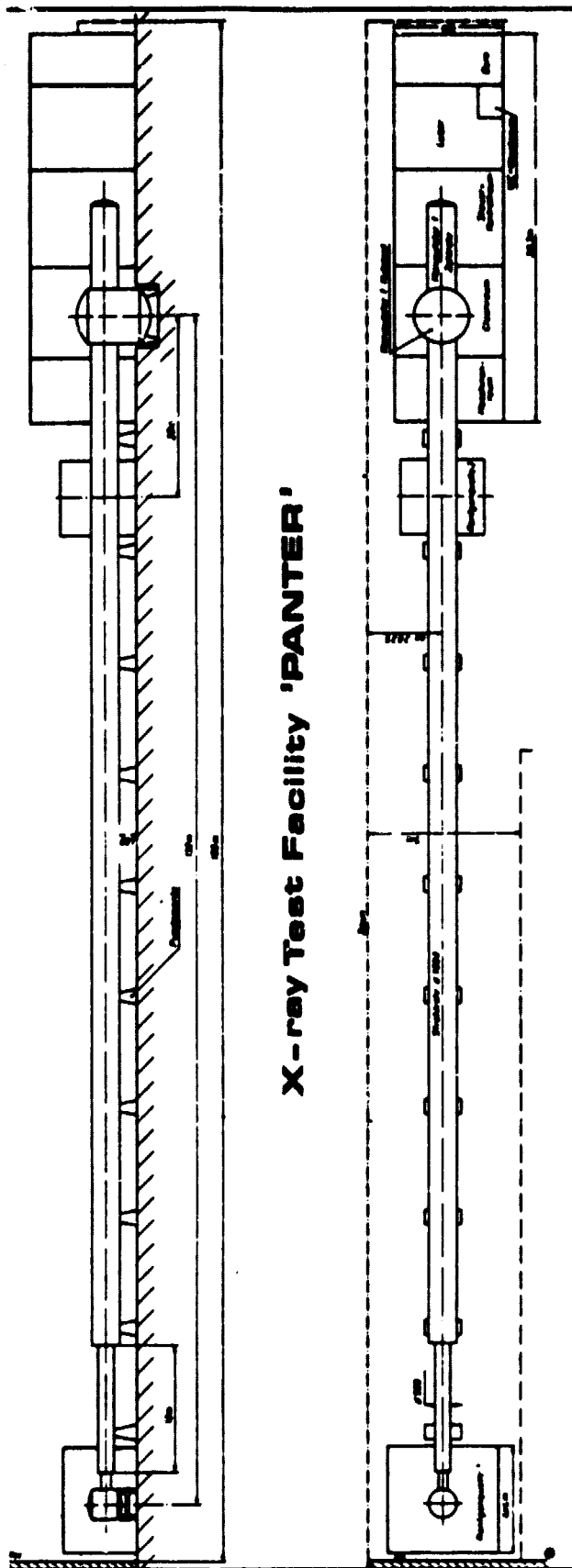
This functional test is referred to as HRI Integrated Baseline Function Test.

6.2 Mirror Assembly/ERI Calibration

The ROSAT will be tested and calibrated at the MPI/MPE 130m X-ray Test Facility (PANTHER) shown in Fig. 6-1. One major goal of this aspect of ground testing will be to determine the Point Spread Function (PSF) of the combined mirror assembly and ERI over the energy range of ROSAT and as a function of field angle. The PSF provides a complete description of the optical behavior of an imaging system and from it can be derived the quantitative response of the system to an object. Using HEAO-2 software, the raw calibration data will be reduced to provide the field angle and energy dependent PSF, the integral of the PSF as a function of radius (encircled energy function), the vignetting function, total effective area, and various one parameter measures of image quality (FWHM, 50% power radius, etc.).

These tests will also determine the focal plane plate scale and map ghost images. The determination of the PSF at large radii requires the accumulation of a large number of counts in the central portion of the image because of the need to acquire a statistically significant number of counts in the "wings" of the PSF. This could result in long test times (due to data rate limitations) and individual pixel counts totalling a significant fraction of their count life. By using a test mask (a 1mm wide metal ribbon) in front of and near the center of the first MCP to block the central portion of the image, high X-ray flux rates can be used with a consequent reduction in test time and accumulated MCP counts.

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X-ray Test Facility 'PANTER'

FIGURE 6-1 X-RAY TEST FACILITY "PANTER" AT MPI/MPE

7.0 GROUND SUPPORT EQUIPMENT

A significant amount of auxiliary equipment is required to support the HRI at various phases of the program. For convenience, we group this auxiliary support equipment into three categories:

1. Electrical Ground Support Equipment (EGSE)
2. Mechanical Ground Support Equipment (MGSE)
3. Life Support System (LSS)

7.1 Electrical Ground Support Equipment (EGSE)

The Electrical Ground Support (EGSE) consisting of both hardware and software must provide several basic functions. These include the following:

1. Command and control of the HRI and external stimuli (pulsars, etc.)
2. Verification of commands
3. Data acquisition from the HRI and transducers (temperature sensors, pressure gauges, etc.)
4. Image display
5. Evaluation of performance and comparison with baseline
6. Provision of hardcopy of test and calibration data
7. Logging of instrument test history
8. Determination of instrument status (voltage levels, temperatures, etc.)
9. Automatic sequencing of test procedures
10. Flagging of out-of-limit behaviour

7.1.1 EGSE Modes of Operation

There are three modes of operation for the HRI:

1. Stand-alone - HRI is operated and evaluated by the SAO-EGSE.
2. FI - No S/C
 (Mode 2) - HRI is integrated into focal assembly controlled by MPE electronics. Data is outputted serially to the MPE EGSE and to SAO EGSE.
3. FI- S/C
 (Mode 3) - HRI is integrated into focal assembly and controlled by MPE electronics. Data is outputted through S/C EGSE through Interface Computer to MPE EGSE and to SAO EGSE in 16 bit parallel blocks.

Connections to the SAO EGSE in the two FI configurations are physically through the MPE EGSE.

The FI (Focal Instrumentation) Modes of operation follow from the flight configuration of the HRI in the ROSAT. This is shown in block diagram form in Fig. 7-1.

There are two functional interfaces to the HRI. Command, control, housekeeping, and power all come from the MPE central electronics in essentially the same way they are provided to the two MPE instruments. The primary data stream and its associated clocking and control are interfaced with the S/C Data Handling System.

Stand-Alone Mode operation is illustrated by Figure 7-2. Solid lines indicate flight interfaces that will exist between either the MPE or the S/C Data Electronics.

The EGSE will provide power, implement commands and control functions and transfer and accept data in the same manner as in the flight configuration. It is equivalent to a S/C simulator although organizationally it is more complicated than that.

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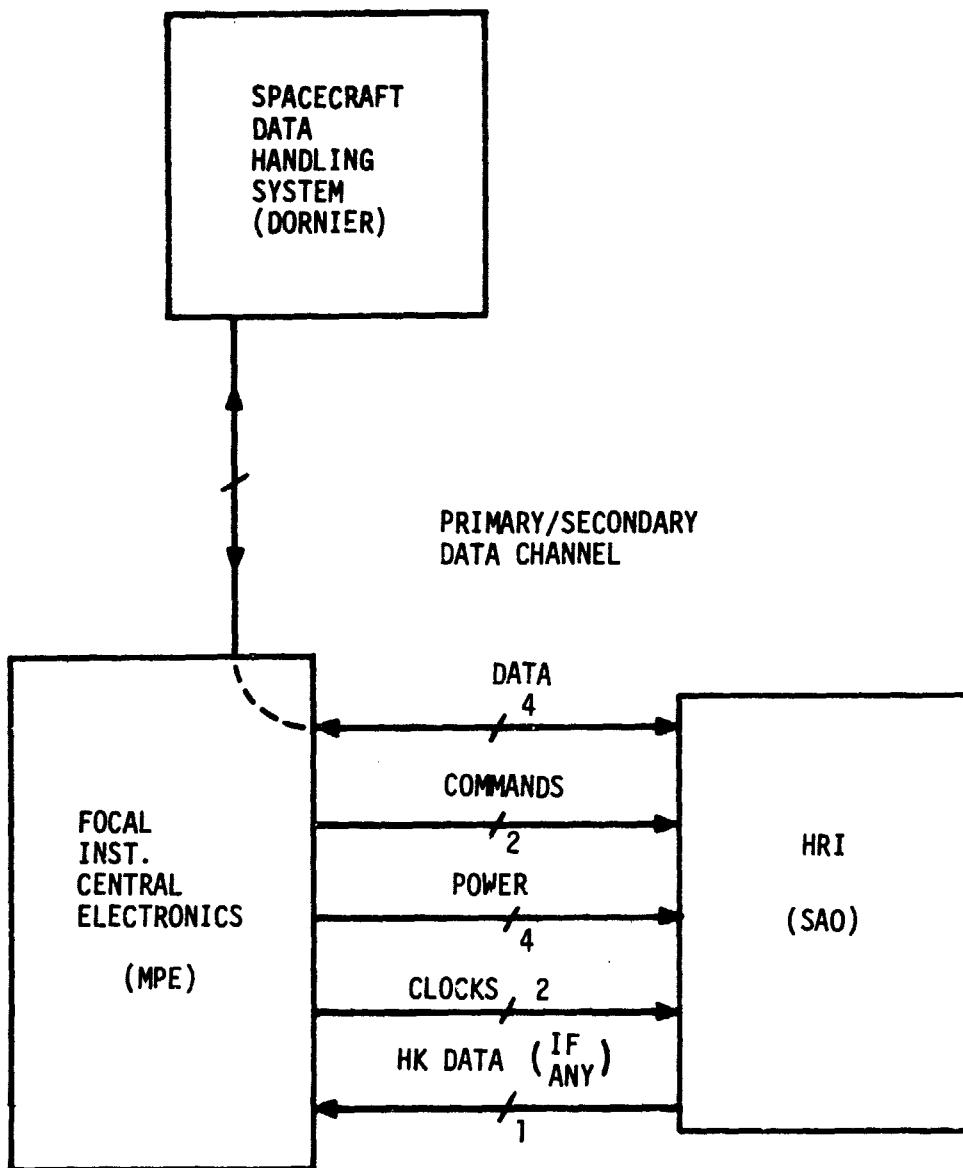


Figure 7-1 - Flight Configuration

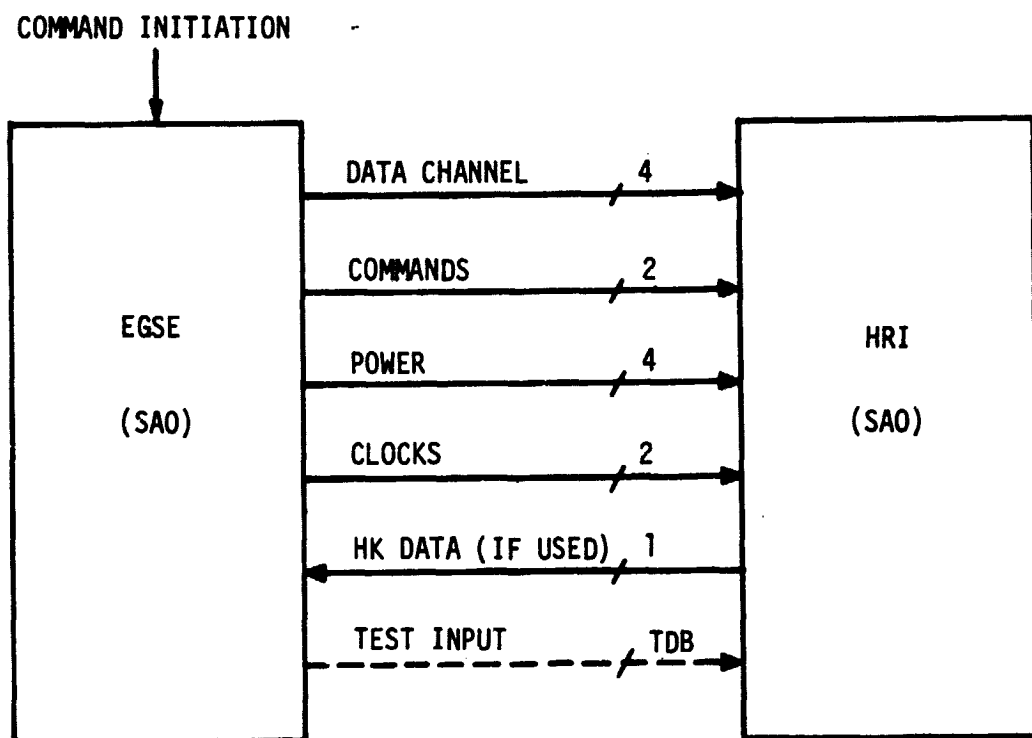


Figure 7-2 - Mode 1 (Stand-Alone)

The EGSE will provide test inputs to the preamp which will bear a fixed relationship to local (EGSE) time. The EGSE will analyze the data and display and record output in appropriate formats. Data output is in 16 bit serial words, as described in TN-ROSAT-SAO-3.

Mode 2 operation is illustrated by Fig. 7-3. This mode is used when the MPE electronics are not connected to the S/C electronics.

In this mode, the MPE EGSE simulates the S/C functions and receives data in the same manner as it is passed to the S/C. Commands to the instruments (including the HRI) and the MPE central electronics are initiated by the MPE EGSE.

The data output is in the form of a stream of 16 bit serial words as described in TN-ROSAT-SAO-3. This output is fed to the MPE EGSE and in parallel to the SAO EGSE.

Mode 3 is used in the fully integrated configuration. The EGSE elements are shown in Fig. 7-4.

Commands to the HRI are initiated by the MPE EGSE but pass through the Dornier (S/C) EGSE for the equivalent of up-linking.

Data is outputted by the Dornier EGSE to an interface computer (provided by DFVLR) which accumulates, reformats, and transfers data to the MPE EGSE.

This data is also displayed in parallel to the SAO EGSE. The data transfer is in the form of 16 bit parallel words as described in TN-ROSAT-SAO-3.

7.2 Mechanical Ground Support Equipment (MGSE)

Mechanical Ground Support Equipment (MGSE) for the proposed program falls into two main categories:

- (1) Shipping containers
- (2) Handling and adapter fixturing

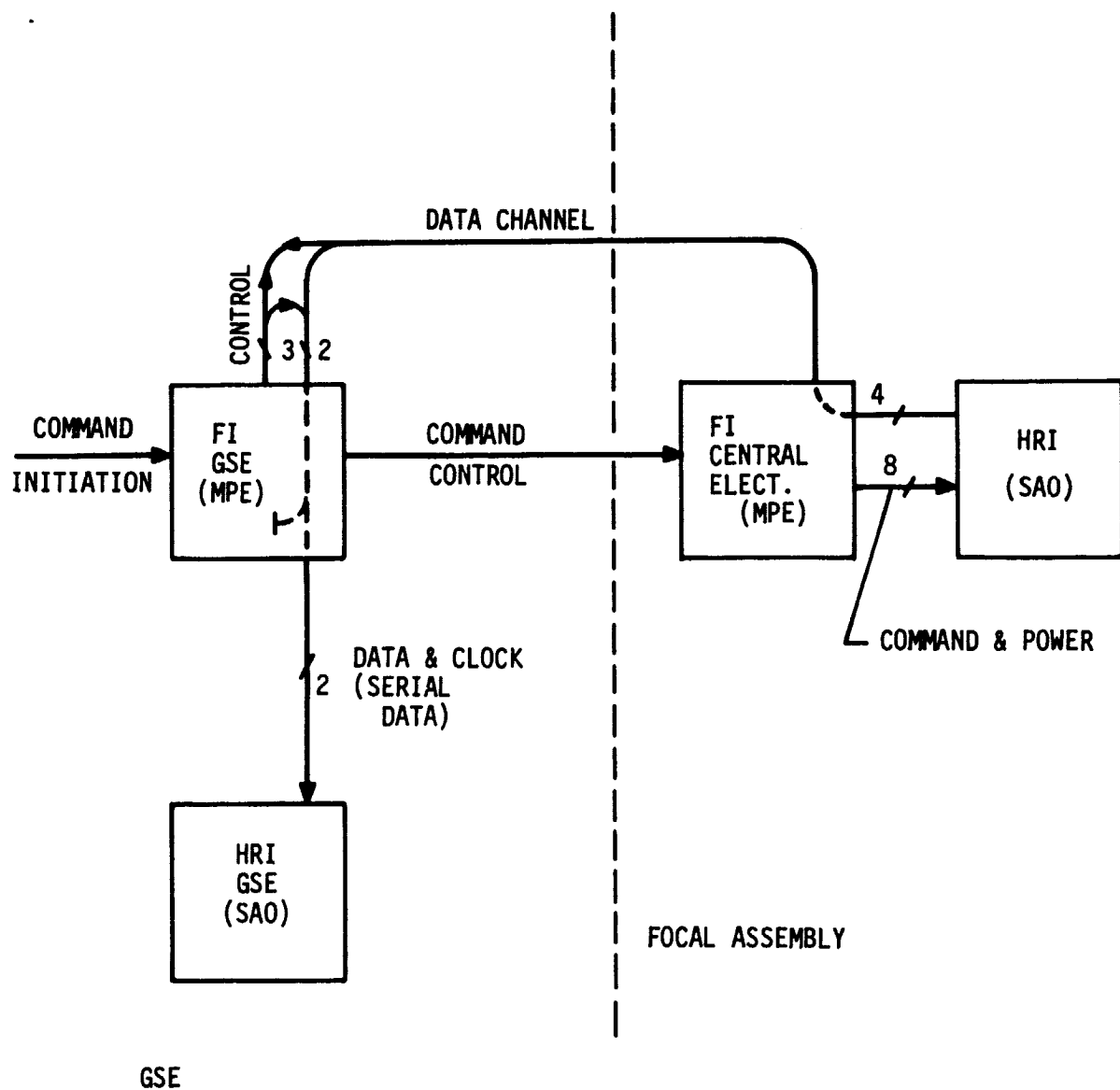


Figure 7-3 - Mode 2 (FI - No S/C)

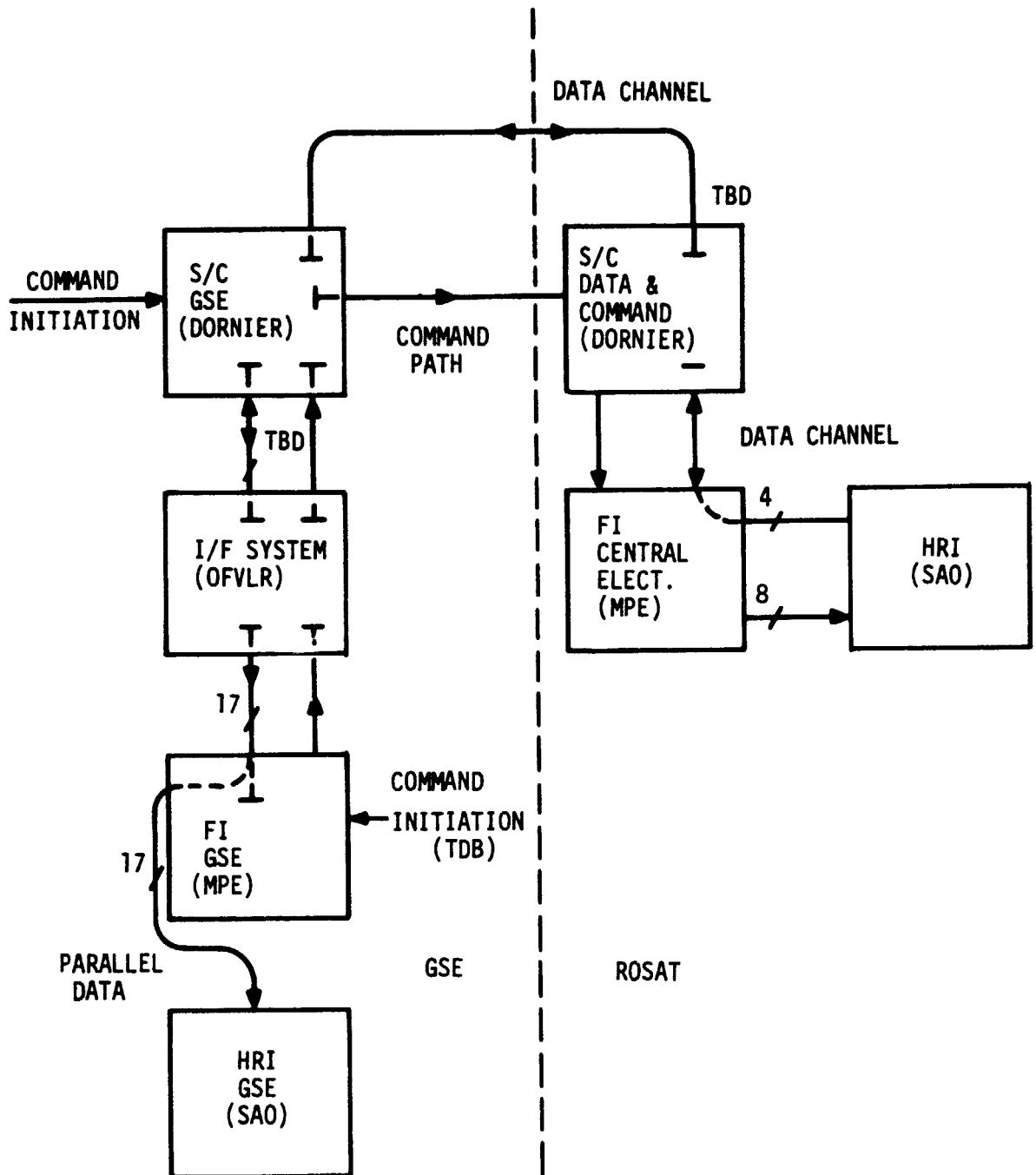


Figure 7-4 - Mode 3 (FI - S/C)

7.2.1 Shipping Containers

Shipping containers are required for the EGSE, the Detector Assembly, the CDEA, assorted cables, spares and documentation, MCP's, and elements of the Life Support System.

A special container is envisioned for the MCP's for shipment from U. of Leicester to SAO. This container will be hermetically tight with input and output valves for filling with dry Nitrogen.

Special containers will also be provided for the Detector Assembly and the CDEA. All other containers are re-usable crates.

7.2.2 Adapter Fixtures

Fixture requirements identified to date are:

- (1) MCP Micropositioner (MCP Tests)
- (2) Vacuum Chamber Adapters (X-ray Testing)
- (3) Support Fixture (Detector Assembly - General)
- (4) Support Fixture (T-V Testing)
- (5) Universal Shake Fixture (Detector Assy. and CDEA)
- (6) Shake Fixture (RS)

7.2.3 Handling Fixtures

SAO will provide adapter interfaces for the MPE insertion and extraction fixtures/tools. A general purpose lifting fixture for the Detector Assembly will also be provided.

7.3 Life Support System (LSS)

The LSS is comprised of two elements; a power unit and a pumping unit.

7.3.1 Power Unit

The Power Unit will be a self-contained AC-DC uninterrupted supply of 28 VDC for the HRI ion pump. It will, in general, travel with the HRI and support the HRI at the various sites either directly or through umbilical connectors.

Input AC power can be either 120 VAC, 1Ø, 60Hz or 230 VAC, 1Ø, 50Hz. Batteries will be kept charged during AC operation and will have the capacity to power the ion pump for TBD hours.

7.3.2 Pumping Unit

The pumping unit is required to re-establish vacuum within the HRI after opening of the front vacuum assembly door.

Three pumps are connected to a vacuum manifold, designed for minimum trapping and interference, which can be connected to the HRI vacuum connector.

A roughing pump is provided for initial pump-down, a diffusion pump for transition range pumping, and a higher capacity ion pump for finish or final pumping of the HRI. This higher capacity pump can also be utilized as a back-up to the integral HRI ion pump except during periods of shipment.

8.0 ENGINEERING MODEL (EM)

In addition to the protoflight HRI instrument proposed in our unsolicited proposal (May, 1981), we strongly recommend the construction and test of an HRI Engineering Model (EM).

The need for an EM has become evident through additional discussions with MPE since May, 1981. First, there is a requirement to support the German activity stream. Second, because the CDEA Housing is essentially a new design, a qualification unit is a highly desirable test vehicle for evaluation of the new design. Both of these requirements are effectively satisfied by providing an Engineering Model.

8.1 ROSAT Program Requirements

The DFVLR program plan includes provisions for an Engineering Model of the entire focal instrument assembly, comprised of the MPE structure, carousel, science instruments, support electronics, and the HRI. This model is required for a variety of purposes, including the support of visualization, mechanical test, electrical test, and thermal test activities. It is possible to support these tests with three separate but simpler models (mass, electrical, and thermal) to satisfy the Dornier requirements/objectives. However, this option does not afford the valuable verification and experience feed-back that would accrue from using an HRI Engineering Model that is almost identical to the Flight Model. This is particularly true for thermal testing of the Detector Assembly where view-factors, surfaces, and near-field power distribution are important (and are difficult to simulate). The EM will also serve as a Prototype/Qualification unit to verify the compatibility of the HRI with the ROSAT environment. This environment, even without STS considerations, is significantly

different from the HRAO-2 environment and, therefore, must be subjected to assessment and evaluation.

8.2 CDEA Housing Considerations

The CDEA consists of HRAO-2 circuit designs, modified HRAO-2 circuit designs, new circuit designs (all packaged in HRAO-style modules) and a totally new housing design.

In addition to addressing STS Fracture Control considerations, it is desirable to build and test a prototype housing to ROSAT qualification levels. When the requirement for Fracture Control management is added, the need for such a unit is evident.

8.3 Test and Evaluation

It is our intent to deliver an Engineering Model which is as similar to the Flight Model as possible and which, in the event of component failure, can serve as a source of spare subassemblies and components. Such an approach maximizes the potential "learning" experience which can accrue from the Dornier tests on the EM as well as establishing confidence in the design, components, and procedures associated with the flight hardware.

Subject to part availability, the electronics will be populated with hi-rel components to permit use of the EM boards as spares. Flight qualified high-voltage and low-voltage supplies also will be utilized in the Engineering Model.

Because there is no hard requirement to operate the Engineering Model HRI as an X-ray detector, the MCP's will not be installed. Also high voltage from the detector and ion pump supplies will not be connected. The cross-grid assembly can be installed if desired. If ROSAT qualification vibration levels are high, the grids can be installed to take advantage of the testing sequence

at Dornier. Dummy data will be generated by a test box whose outputs are applied to the test inputs of ten preselected Detector Assembly preamplifiers (test input connectors are exposed). Because there is no vacuum nor are there MCP's within the detector cavity, the door can also be exercised to verify performance. All other functions are essentially identical to the flight model requirements.